

# OPTICAL SHEET, POLARIZER AND LIQUID-CRYSTAL DISPLAY DEVICE

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

[0001]

The present invention relates to an optical sheet by which light between polarizers disposed in the form of crossed-Nicol can be cut off at wide-ranging azimuth angles so that a good-display-quality vertically oriented liquid-crystal display device which is excellent in viewing angle and contrast can be formed.

The present application is based on Japanese Patent Application No. 2000-284760, which is incorporated herein by reference.

### 2. Description of the Related Art

[0002]

Even in the case where light between polarizers disposed in the form of crossed-Nicol was cut off in a normal-line (frontal) direction in which an axis of transmission and an axis of absorption functioned normally, there was heretofore a problem that light leakage occurred in a displaced viewing azimuth crossing the optical axis so that the intensity of leakage light increased gradually as the angle of oblique viewing increased. The problem was revealed as a disadvantage that

display quality was deteriorated by reduction in display contrast due to light leakage in a viewing azimuth displaced from the optical axis when the polarizers were disposed on opposite sides of the liquid-crystal cell to function as a polarizer and an analyzer to thereby form a liquid-crystal display device.

[0003]

In a vertically oriented (VA) liquid-crystal cell in which liquid-crystal molecules were oriented approximately vertically with respect to a cell substrate so that light was able to be transmitted with little change of the plane of polarization, when polarizers were disposed in the form of crossed-Nicol on opposite sides of the cell, light was apt to be cut off in a frontal (normal) direction of a display panel perpendicular to the cell substrate in an inoperative mode having no external voltage applied to thereby make it possible to form good black display easily, in comparison with a TN liquid-crystal cell or the like in which liquid-crystal molecules were oriented horizontally with respect to a cell substrate so that display quality was apt to be deteriorated by light leakage owing to birefringence of the liquid-crystal cell at light transmission. However, the problem that contrast was deteriorated by light leakage in an oblique viewing azimuth displaced from the optical axis of the polarizers because of the aforementioned problem

caused by the polarizers still remained, even if a phase retarder exhibiting refractive index anisotropy of  $n_x = n_y > n_z$  as disclosed in Unexamined Japanese Patent Publication Sho.

62-210423 was used in combination with the vertically oriented liquid-crystal cell for compensating for birefringence of the liquid-crystal cell caused by oblique viewing.

#### SUMMARY OF THE INVENTION

[0004]

An object of the present invention is to develop a member capable of suppressing light leakage even in an oblique viewing azimuth displaced from the optical axis between polarizers disposed in the form of crossed-Nicol to thereby obtain a vertically oriented liquid-crystal display device which is good in display quality and which is excellent in contrast at wide-ranging viewing angles.

[0005]

According to an aspect of the present invention, there is provided an optical sheet constituted by a retardation film, and a transparent layer provided on one of opposite surfaces of the retardation film. The retardation film exhibits  $N_z = (n_x - n_z) / (n_x - n_y)$  in a range of from 0.6 to 0.9 and  $(n_x - n_y)d$  in a range of from 200 to 350 nm in which  $d$  is a thickness of the retardation film,  $n_z$  is a refractive index in a direction

of a Z axis expressing a direction of the thickness  $d$  of the retardation film,  $n_x$  is a refractive index in a direction of an X axis expressing a direction of the retardation film in a plane perpendicular to the Z axis while the X axis also expresses a direction of the highest in-plane refractive index, and  $n_y$  is a refractive index in a direction of a Y axis expressing a direction of the retardation film perpendicular both to the Z axis and to the X axis. And the transparent layer has a thickness not larger than  $10\ \mu\text{m}$  and exhibits refractive index anisotropy of  $n_x \neq n_y > n_z$ .

[0006]

According to another aspect of the present invention, there is provided a polarizer constituted by a laminate of an optical sheet as defined above, and a polarizing film.

According to a further aspect of the present invention, there is provided a liquid-crystal display device constituted by a vertically oriented liquid-crystal cell, and a pair of polarizers as defined above, the pair of polarizers being provided on opposite sides of the cell. Further, a transparent layer in each of the pair of polarizers is positioned on corresponding one of opposite sides of the cell, and the pair of polarizers provided on the opposite sides of the cell are disposed in the form of crossed-Nicol. According to a still further aspect of the present invention, there is provided a

liquid-crystal display device constituted by a vertically oriented liquid-crystal cell, and a pair of polarizers each comprising a laminate of the above optical sheet and a polarizing film, wherein the polarizing film is disposed on a side of the optical sheet opposite to the transparent layer side of the optical sheet so that the X axis direction of the retardation film of the optical sheet is parallel with an axis of absorption of the retardation film. Further, the pair of polarizers is disposed in the form of crossed-Nicol on opposite sides of the liquid-crystal cell, and at least one phase retarder is disposed between the liquid-crystal cell and one or both of the polarizers. Still further, the phase retarder exhibits refractive index anisotropy of  $n_x \neq n_y > n_z$ , and a sum of absolute values of thicknesswise retardations defined by a product of  $\{(n_x + n_y)/2 - n_z\}$  and a layer thickness of each of transparent layers of the polarizers disposed on the opposite sides of the liquid-crystal cell and an absolute value of a thicknesswise retardation of the phase retarder is in a range of from 0.5 times to 1.3 times as large as an absolute value of a thicknesswise retardation of the liquid-crystal cell.

[0007]

When the optical sheet according to the present invention is used as a transparent protective layer or the like, a polarizer can be formed on the optical sheet. When polarizers defined

above are disposed in the form of crossed-Nicol on opposite sides of a vertically oriented liquid-crystal cell, light can be cut off in the direction of the optical axis of the polarizers in the same manner as that in the background art while  
5 birefringence of the liquid-crystal cell in an oblique viewing direction can be compensated for. Hence, light leakage can be suppressed even in an azimuth displaced from the optical axis. Accordingly, there can be formed a vertically oriented liquid-crystal display device which is good in display quality  
10 and which is excellent in contrast at wide-ranging viewing angles. Because the optical sheet can be used as a transparent layer for protecting a polarizing film, reduction in thickness of the polarizer or the liquid-crystal display device can be attained.

15 Features and advantages of the invention will be evident from the following detailed description of the preferred embodiments described in conjunction with the attached drawings.

#### 20 BRIEF DESCRIPTION OF THE DRAWING

Fig. 1 is a sectional view showing an embodiment of the present invention.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS



films 2 each including a transparent protective layer 21, and a vertically oriented liquid-crystal cell 3.

[0010]

As each of the retardation films, it is possible to use a suitable one which exhibits  $N_z = (n_x - n_z)/(n_x - n_y)$  in a range of from 0.6 to 0.9, preferably in a range of from 0.7 to 0.8, and a retardation  $(n_x - n_y)d$  in a range of from 200 to 350 nm, preferably in a range of from 230 to 300 nm, more preferably in a range of from 250 to 280 nm in which  $d$  is the thickness of the retardation film,  $n_z$  is the refractive index in a direction of a Z axis expressing a direction of the thickness  $d$  of the retardation film,  $n_x$  is the refractive index in a direction of an X axis expressing a direction of the retardation film in a plane perpendicular to the Z axis while the X axis also expresses a direction of the highest in-plane refractive index, and  $n_y$  is the refractive index in a direction of a Y axis expressing a direction of the retardation film perpendicular both to the Z axis and to the X axis.

[0011]

Any suitable polymer may be used for forming the retardation film without any particular limitation. Examples of the polymer may include: polycarbonate or polyallylate; polysulfone or polyolefin such as polypropylene; polyester such as polyethylene terephthalate or polyethylene naphthalate;



norbornene polymer or acrylic polymer; styrene polymer or cellulose polymer; a mixture polymer formed by selecting two kinds of polymers or three or more kinds of polymers from these polymers; and so on.

5 [0012]

For example, the retardation film having the  
aforementioned characteristic can be obtained as a drawn film  
or the like constituted by a polymer film drawn by a suitable  
system such as uniaxial drawing or biaxial drawing. Preferably,  
10 the retardation film is a polymer film in which optical  
characteristic such as retardation can be controlled in  
accordance with the change of the kind of polymer, the drawing  
condition, and so on, and which is excellent in light  
transmittance and small in orientation irregularity and  
15 retardation irregularity. The retardation film may be a  
suitable one which is made from a polymer film provided with  
a heat-shrinkable film bonded to the polymer film so that the  
thicknesswise refractive index of the polymer film is controlled  
under the action of shrinking force of the heat-shrinkable film  
20 by heating. Alternatively, the retardation film may be  
provided as a multilayer film of two or more retardation layers  
in order to control optical characteristic.

[0013]

The transparent film provided on one of opposite surfaces

of the retardation film has a thickness not larger than 10  $\mu\text{m}$  and exhibits refractive index anisotropy of  $n_x \doteq n_y > n_z$  in which  $n_z$  is the refractive index in a direction of a Z axis expressing a direction of the thickness of the transparent film,  $n_x$  is the refractive index in a direction of an X axis expressing a direction of the transparent film in a plane perpendicular to the Z axis, and  $n_y$  is the refractive index in a direction of a Y axis expressing a direction of the transparent film perpendicular both to the Z axis and to the X axis. The relation  $n_x \doteq n_y$  means that a variation of 10 nm or less on the basis of the retardation given by the product of  $|n_x - n_y|$  and the thickness of the transparent layer can be allowed. Hence, the relation  $n_x \doteq n_y$  includes the case of  $n_x = n_y$ .

[0014]

When the thickness of the transparent layer is selected to be not larger than 10  $\mu\text{m}$ , reduction in thickness of the optical sheet can be achieved so that the layer can be used as a transparent layer for protecting the polarizing film. The transparent layer can be formed from a suitable material exhibiting the aforementioned refractive index anisotropy and by a suitable system. A coating system using an organic material is used preferably from the point of view of forming a flexible thin layer easily, and so on. A suitable system such as gravure coating, die coating or dip coating can be used as the coating

system. A system of transferring a coating solution layer or a coating film provided on another film may be also used.

[0015]

The material preferably used for forming the transparent layer from the point of view of achieving the refractive index anisotropy of  $n_x \neq n_y > n_z$  while satisfying the aforementioned reduction in film thickness is a material which can form a cholesteric liquid-crystal layer constituted by a cholesteric liquid-crystal polymer, a chiral-agent-mixed nematic liquid-crystal polymer, a compound capable of forming such a liquid-crystal polymer by photopolymerization or thermalpolymerization, or the like. Especially, the material capable of forming a cholesteric liquid-crystal layer used preferably from the point of view of achieving bright display is a material which does not exhibit selective reflection characteristic in a visible light region.

[0016]

That is, the cholesteric liquid-crystal layer exhibits characteristic of selectively reflecting a part of light with wavelengths near to the wavelength  $n_c P$  of incident light in parallel to a helical axis as circularly polarized light in one of left and right directions with the wavelength  $n_c P$  as its center wavelength when  $n_c$  is the average refractive index on the basis of the helically oriented state of the cholesteric

liquid-crystal layer, and P is the helical pitch. Hence, if the region of the selectively reflected light appears in a visible light region, the intensity of light allowed to be used for display is reduced disadvantageously. Any suitable orientation system such as a process of forming an oriented film by a rubbing treatment or an orientation process using application of electric field or magnetic field can be applied to the formation of the cholesteric liquid-crystal layer.

[0017]

Incidentally, the thickness of the transparent layer is generally selected to be not smaller than 0.1  $\mu\text{m}$ , particularly not smaller than 0.5  $\mu\text{m}$ , more particularly not smaller than 1  $\mu\text{m}$ . The refractive index anisotropy of  $n_x \neq n_y > n_z$  in the transparent layer means the fact that  $n_z$  is smaller than each of  $n_x$  and  $n_y$ . The refractive index difference is not particularly limited and can be determined suitably in accordance with the birefringent characteristic, or the like, of the vertically oriented liquid-crystal cell to be compensated for.

[0018]

Even in the case where the optical sheet according to the present invention is laminated on a background-art polarizer, the aforementioned effect of preventing light leakage can be obtained. The polarizer preferred from the point of view of

handling properties due to reduction in thickness or increase in flexibility is, however, a polarizer constituted by an optical sheet 1 defined above, and a polarizing film 2 having a surface on which the optical sheet 1 is laminated as a transparent protective layer, as shown in Fig. 1. Particularly from the point of view of improvement in the effect of compensating for the vertically oriented liquid-crystal cell, the polarizing film 11 (13) is laminated on a side of the optical sheet 1 opposite to the transparent layer 12 (14) side so that the X axis direction (the direction of the highest in-plane refractive index) of the retardation film 11 (13) is directed as parallel as possible with the absorption axis thereof.

[0019]

As the polarizing film, any suitable one in accordance with the background art may be used without particular limitation. That is, it is possible to use a film of a hydrophilic polymer, such as polyvinyl alcohol, partially formalized polyvinyl alcohol or partially saponified ethylene-vinyl acetate copolymer, which is made to absorb a dichromatic material containing iodine or/and a dichromatic dye such as an azo dye, an anthraquinone dye or a tetrazine dye so that the resulting film is drawn and oriented.

[0020]

The optical sheet and the polarizing film may be formed

to be separated from each other. It is, however, preferable from the point of view of preventing displacement of the optical axis and preventing entrance of foreign matter such as dust that the optical sheet and the polarizing film are fixed to each other. A suitable system such as a bonding system using a transparent adhesive layer can be applied to the fixation (lamination). The adhesive agent or the like used in the bonding system is not particularly limited in kind. An adhesive agent which does not require any high-temperature process for hardening and drying the adhesive agent in the bonding process is used preferably from the point of view of preventing the optical characteristic of the constituent members from changing. That is, an adhesive agent which requires neither long-term hardening process nor long drying time is used preferably. From this point of view, a hydrophilic polymer adhesive agent or an adhesive layer may be used preferably.

[0021]

A transparent adhesive agent made of a suitable polymer such as acrylic polymer, silicon polymer, polyester, polyurethane, polyether or synthetic rubber can be used for forming the aforementioned adhesive layer. Particularly, an acrylic adhesive agent is used preferably from the point of view of optical transparency, adhesive characteristic, weather resistance, etc. As for the adhesive layer, one adhesive layer

may be provided on one of opposite surfaces of the polarizer, or two adhesive layers may be provided on the opposite surfaces of the polarizer, for the purpose of bonding the liquid-crystal cell to a subject to be bonded in accordance with the necessity.

5 In this case, it is preferable that a separator or the like is temporarily attached to the adhesive layer to prevent the surface of the adhesive layer from contamination or the like before the adhesive layer is exposed to the outside for practical use.

10 [0022]

When the surface of the polarizing film on a side opposite to the optical sheet side in the polarizer is exposed, a transparent protective film may be provided on the surface for the purpose of reinforcement, improvement of heat resistance and moisture resistance, etc. The transparent protective layer can be formed in accordance with the background art. That is, the transparent protective layer can be formed as a coating layer of a suitable resin such as triacetyl cellulose or as a layer of a laminate of resin films. The transparent protective layer may contain fine particles for the purpose of diffusing light, roughening the surface, etc.

[0023]

The polarizer may be formed as a plate having a suitable functional layer such as a protective layer used for various

purposes of water resistance, and so on, or an anti-reflection layer or/and an anti-glare layer used for the purpose of preventing surface reflection, in one or each of opposite surfaces of the polarizer, in the same manner as described above in the transparent protective layer. The anti-reflection layer can be formed suitably as a light-coherent film such as a fluorine polymer coat layer or a multilayer metal deposited film. The anti-glare layer can be formed by a suitable system in which surface-reflected light is diffused by a coating layer of a resin containing fine particles or by a fine asperity structure given to the surface by a suitable system such as embossing, sandblasting or etching.

[0024]

Examples of the fine particles include inorganic particles and organic particles with a mean particle size of from 0.5 to 20  $\mu\text{m}$ . The inorganic particles which may be electrically conductive are made of silica, calcium oxide, alumina, titania, zirconia, tin oxide, indium oxide, cadmium oxide, antimony oxide, etc. The organic particles are made of crosslinked or non-crosslinked suitable polymers such as polymethyl methacrylate and polyurethane. One member or a combination of two or more members suitably selected from the inorganic particles and the organic particles may be used as the fine particles.



[0025]

The optical sheet or polarizer according to the present invention can be used preferably for suitable purposes such as the purpose of forming a liquid-crystal display device.

5 Particularly, the polarizer, in which a polarizing film is laminated on the surface of the optical sheet opposite to the transparent layer side so that the direction of the highest in-plane refractive index of the retardation film is directed as parallel as possible with the absorption axis thereof, can be used preferably for optical compensation for the vertically oriented liquid-crystal cell. The liquid-crystal display device can be formed by arranging polarizers in the form of crossed-Nicol on opposite sides of the vertically oriented liquid-crystal cell 3 while positioning the transparent layers 12 and 14 of the polarizers on the opposite sides of the liquid-crystal cell.

[0026]

The polarizers preferred from the point of view of achieving wide-ranging viewing angles by the high-grade compensation are polarizers which are disposed on both sides of the liquid-crystal cell and in which the sum of the absolute values of the thicknesswise retardations of the transparent layers in the polarizers is in a range of from 0.5 time to 1.3 times, particularly in a range of from 0.7 time to 1.0 time

as large as the absolute value of the thicknesswise retardation of the liquid-crystal cell. Incidentally, the thicknesswise retardation in each of the transparent layers is defined by the product of  $\{(n_x + n_y)/2 - n_z\}$  and the thickness of the transparent layer.

[0027]

In the above description, when the sum of the absolute values of the thicknesswise retardations of the transparent layers does not satisfy the predetermined magnifying power, a phase retarder 4 may be disposed between the vertically oriented liquid-crystal cell 3 and the polarizer 2 so that the sum of the absolute values of the thicknesswise retardations of the transparent layers in the polarizers disposed on the opposite sides of the liquid-crystal cell and the absolute value of the thicknesswise retardation of the phase retarder can be adjusted to be in a range of from 0.5 times to 1.3 times, preferably in a range of from 0.7 to 1.0 times as large as the absolute value of the thicknesswise retardation of the liquid-crystal cell.

[0028]

In the aforementioned case, a phase retarder or a pair of phase retarders may be disposed between the liquid-crystal cell and one or both of the polarizers which are disposed in the form of crossed-Nicol on the opposite sides of the

liquid-crystal cell. When such a pair of phase retarders are disposed between the liquid-crystal cell and both of the polarizers, adjustment is preferably performed to satisfy the aforementioned magnifying power in the condition that the absolute values of the thicknesswise retardations of the phase retarders are summed up.

[0029]

As the phase retarder, it is possible to use a suitable one exhibiting refractive index anisotropy of  $n_x \approx n_y > n_z$  because the phase retarder is provided for correcting an excess or a shortage of the magnifying power of the thicknesswise retardation of the transparent layer in the optical sheet, generally, because the phase retarder is provided for compensating for the shortage of the magnifying power. Hence, the refractive index anisotropy of  $n_x \approx n_y > n_z$  of the phase retarder may be similar to the case of the transparent layer described above. The phase retarder having such a characteristic can be obtained in the same manner as described above in the retardation film. Incidentally, the phase retarder used may be provided as a laminate of two or more retardation layers to adjust the optical characteristic thereof.

[0030]

In the present invention, the liquid-crystal display

device can be formed in accordance with the background art without any particular limitation except that the aforementioned polarizers are disposed in the form of crossed-Nicol on opposite sides of the vertically oriented liquid-crystal cell. Hence, a system for operating the liquid-crystal cell is not particularly limited. When the liquid-crystal display device is to be formed, suitable optical devices such as a phase retarder, a light-diffusing plate, a backlight, a light-condensing sheet, a reflection plate, etc. may be disposed suitably in accordance with the necessity.

[0031]

#### Example 1

A rubbed and oriented film was formed on one of opposite surfaces of a retardation film constituted by a drawn film of polycarbonate and exhibiting  $N_z$  of 0.75 and  $(n_x - n_y)d$  of 260 nm. A cholesteric liquid crystal (CB-15 made by Dai Nippon Ink and Chemicals, Inc.) was applied onto the rubbed and oriented film and dried so as to form a transparent film constituted by a coating film which had a thickness of 5  $\mu\text{m}$  and which exhibited refractive index anisotropy of  $n_x \approx n_y > n_z$ . Thus, an optical sheet was obtained.

[0032]

On the other hand, a polyvinyl alcohol film was dyed in an aqueous solution containing iodine and then uniaxially drawn

between different-circumferential-velocity rolls in an aqueous solution containing boric acid to thereby obtain a polarizing film. The drawn film-exposed side of the optical sheet was bonded onto one of opposite surfaces of the polarizing film through a polyvinyl alcohol adhesive agent. A triacetyl cellulose film was bonded onto the other surface of the polarizing film through a polyvinyl alcohol adhesive agent. Thus, a polarizer was obtained. Incidentally, the optical sheet was laminated on the polarizing film so that the direction (nx) of the highest in-plane refractive index of the drawn film in the optical sheet is directed in parallel with the axis of absorption of the polarizing film.

[0033]

Polarizers as defined above were disposed in the form of crossed-Nicol on opposite sides of a vertically oriented liquid-crystal cell while the optical sheet in each of the polarizers was disposed on the cell side. Thus, a liquid-crystal display device was formed. In this case, the sum of the absolute values of the thicknesswise retardations of the transparent layers in the polarizers disposed on the opposite sides of the liquid-crystal cell was 0.8 times as large as the absolute value of the thicknesswise retardation of the liquid-crystal cell. The contrast ratio was measured in the condition that the obtained liquid-crystal display device was

viewed obliquely at an inclination angle of 70 degrees with respect to the normal line in an azimuth displaced by 45 degrees from the optical axis of the polarizers disposed in the form of crossed-Nicol (this condition applies to the following Comparative Examples). As a result, the contrast ratio was 12.

[0034]

#### Example 2

Optical sheets and polarizers were obtained in the same manner as that in Example 1 except that the thickness of the transparent layer made of a coating film was set to be 2  $\mu\text{m}$ . A liquid-crystal display device was formed by use of the polarizers. In this case, a phase retarder which was made of a drawn film of polycarbonate exhibiting refractive index anisotropy of  $n_x \doteq n_y > n_z$  and in which the absolute value of the thicknesswise retardation of the phase retarder was 0.48 times as large as the absolute value of the thicknesswise retardation of the liquid-crystal cell was interposed between the liquid-crystal cell and the visual-side polarizer. Hence, controlling was performed so that the sum of the absolute value of the thicknesswise retardation of the phase retarder and the absolute values of the thicknesswise retardations of the transparent layers in the polarizers disposed on the opposite sides of the liquid-crystal cell was 0.8 times as large as the

absolute value of the thicknesswise retardation of the liquid-crystal cell. The contrast ratio in the predetermined viewing direction in the obtained liquid-crystal display device was 12.

5 [0035]

#### Comparative Example 1

10 A polarizer was obtained in the same manner as that in Example 1 except that the optical sheet was replaced by a triacetyl cellulose film. Polarizers obtained thus were used to form a liquid-crystal display device. The contrast ratio in the predetermined oblique viewing direction was 2.

[0036]

#### Comparative Example 2

15 A liquid-crystal display device was formed in the same manner as that in Comparative Example 1 except that a retardation film which was constituted by a drawn film of polycarbonate exhibiting refractive index anisotropy of  $n_x \approx n_y > n_z$  and in which the sum of the absolute values of the thicknesswise retardations was 0.8 times as large as the absolute value of the thicknesswise retardation of the liquid-crystal cell was interposed between one of the polarizers and the liquid-crystal cell to thereby be a compensator for the liquid-crystal display device. The contrast ratio in the predetermined oblique viewing direction was 6.

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Although the invention has been described in its preferred form with a certain degree of particularity, it is understood that the present disclosure of the preferred form can be changed in the details of construction and in the combination and arrangement of parts without departing from the spirit and the scope of the invention as hereinafter claimed.

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